CONVERGENT/DIVERGENT SEGMENTED EXHAUST NOZZLE

[0001] This application is a continuation of United States Patent Application No. 10/087,582 filed on February 28, 2002, presently allowed, the disclosure of which is incorporated herein by reference.

FIELD OF THE INVENTION

[0002] This invention relates to exhaust nozzles used with turbofan engines, and more particularly to an exhaust nozzle used with a turbofan jet engine for reducing the noise of the exhaust gasses emitted from the engine without suppressing the flow of exhaust gasses through the exhaust nozzle.

BACKGROUND OF THE INVENTION

[0003] The reduction of exhaust flow jet noise from turbofan aircraft engines is essential to meeting current and anticipated future government regulatory requirements for Airplane Type Certification, as well as numerous local airport noise ordinances. There have been many attempts to accomplish jet exhaust noise reduction through various modifications to the exhaust nozzle of the engine. While many of these attempts have produced some degree of noise reduction, they have also resulted in adverse impacts on engine operability and/or engine operability limit related performance.

[0004] A jet noise reducing nozzle segment is typically triangular in planform and is contoured to increasingly immerse or extend into the exhaust flow with distance along its length. Multiple segments attached to the exit of a conventional exhaust nozzle are typically used to form a jet noise reducing segmented exhaust nozzle. The effective flow area of the exhaust nozzle is reduced when nozzle segments are employed due to the presence of portions of the nozzle segment projecting into the exhaust gas flow path. These portions, in effect, present additional blockage to the oncoming exhaust gas flow. On a turbofan engine, the additional blockage results in reduced fan flutter margin which can negatively impact fan aero-elastic structural stability. It also can cause increased exhaust gas temperatures which can negatively

impact turbine life. Still further, it can result in reduced engine compressor stall margin which can negatively impact engine core operation stability. Individually or together, these impacts can be of such significance that they prevent the implementation of the noise-reducing device on a jet engine. This impact is particularly hard felt on older jet engine designs that have been "thrust bumped" to near their operational limits.

[0005] With ever increasing stringency of new community noise limitations, existing aircraft types currently in service, as well as new designs for future aircraft, will require new jet noise control technology. This increased stringency could potentially present a threat to the introduction of future aircraft designs. Moreover, ever stricter community noise limitations, if not addressed by suitable noise reduction technology, could impede the introduction of derivative aircraft platforms.

[0006] Accordingly, there exists a need to further reduce the noise produced by turbofan jet aircraft engines without imposing an unacceptable reduction in engine operability margins or operability limit related performance.

SUMMARY OF THE INVENTION

[0007] The present invention is directed to a segmented exhaust nozzle that effectively reduces the exhaust jet noise generated by a turbofan jet aircraft engine without adversely impacting engine operability or operability limit related performance. The exhaust nozzle is formed by a fan inner wall and a fan outer wall. The inner and outer walls cooperatively form an annular exhaust gas flow path therebetween. The walls further define a nozzle throat area and a nozzle exit area from which the exhaust gasses of a turbofan engine associated with the exhaust nozzle are emitted.

[0008] The exhaust nozzle of the present invention provides a first region in which one of the inner or outer walls curves gradually towards the other, thereby presenting reduced cross-sectional area to exhaust gas flow in this region forming an aerodynamic throat. A second region, through the segmented portion of the nozzle and downstream of the first region, is formed

by the one wall curving away from the other wall to produce a region of increased cross-sectional area to exhaust gas flow. Importantly, the second region forms an exhaust gas nozzle exit area which has an effective cross sectional area approximately equal to a conventional exhaust gas nozzle exit area. This is in contrast to previously developed, segmented exhaust nozzles in which the exhaust gas nozzle exit area is smaller in cross section than a conventional exhaust nozzle exit area. This difference effectively serves to eliminate the negative impact on engine operability and operability limit related performance introduced by previous segmented exhaust nozzle configurations while still providing a significant reduction in engine jet noise.

[0009] The present invention thus reduces significantly the exhaust gas flow suppression that would typically be present with previous forms of segmented exhaust nozzles by presenting a geometric inflection through the flow control region of the nozzle. The inflective profile creates a conversion-divergent, cross sectional shape to the nozzle wall. The result is a net zero change in exhaust flow characteristic and a net zero change in segmented nozzle noise suppression effectiveness.

[0010] Further areas of applicability of the present invention will become apparent from the detailed description provided hereinafter. It should be understood that the detailed description and specific examples, while indicating the preferred embodiment of the invention, are intended for purposes of illustration only and are not intended to limited the scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The present invention will become more fully understood from the detailed description and the accompanying drawings, wherein:

[0012] Figure 1 is a highly simplified side view of an exhaust nozzle in accordance with a preferred embodiment of the present invention;

[0013] Figure 2 is a highly simplified cross sectional view of a portion of an exhaust nozzle in accordance with section line 2-2 in Figure 1 illustrating the curvature of the convergent/divergent segmented exhaust nozzle of the present invention;

[0014] Figure 3 is a bar graph illustrating test results for noise reduction under various operating conditions;

[0015] Figure 4 is a graph illustrating the overall sound pressure level relative to a body station of an aircraft; and

[0016] Figure 5 is a graph illustrating the nozzle discharge characteristic of the segmented exhaust nozzle of the present invention as compared to that of a conventional exhaust nozzle flow characteristic and the flow characteristic of previous designed segmented nozzles.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0017] The following description of the preferred embodiment(s) is merely exemplary in nature and is in no way intended to limit the invention, its application, or uses.

[0018] Referring to Figure 1, there is shown a segmented exhaust nozzle 10 in accordance with a preferred embodiment of the present invention. The exhaust nozzle 10 is particularly adapted for use with high bypass ratio turbofan jet engines. In this example, an external plug 11 is disposed within a housing structure forming a nacelle 18 along an imaginary axial center line "C_L" of the nacelle.

[0019] Referring to Figure 2, there is shown a portion of the segmented exhaust nozzle 10. The segmented exhaust nozzle 10 includes a fan nozzle inner wall 12 and a fan nozzle outer wall 14 spaced apart from the inner wall 12. Cooperatively, the walls 12 and 14 form an annular exhaust

gas flow path 16. The exhaust nozzle 10 is further typically contained within the nacelle 18, which also houses the turbofan jet engine (not shown).

[0020] The outer wall 14 of the segmented exhaust nozzle 10 comprises a unique contour which effectively serves to reduce the exhaust jet noise generated by the turbofan jet engine without negatively impacting the operability or operability limit related performance of the engine. The outer wall 14 includes a portion curving gradually inwardly toward the inner wall 12 from a first point 20 to a second point 22 forming an aerodynamic choke point. From point 22, the outer wall 14 changes direction and curves gradually away from the inner wall 12 to a third point 24. Thereafter, the outer wall 14 again begins to curve towards the inner wall 12 to a fourth point 26. This is the segmented region of the nozzle. Point 22 also defines the location of the exhaust nozzle throat area ("A_{throat}") while an integration of points 24 through 26 comprises the segmented exhaust nozzle exit area ("A_{exit}"). For comparison purposes, "A_{E1}" defines a point at which a conventional exhaust nozzle exit area would be located. Also, "A_{E1} through A_{E2}" defines an exhaust nozzle exit area for a previously developed, typical segmented exhaust nozzle.

[0021] From Figure 2 it can be seen that points 20-24 define a first region in which the outer wall 14 forms an arcuate protrusion which projects into the exhaust gas flow path 16. The axial distance between points 24 and 26 defines a region of increased cross-sectional area to the exhaust gas flow. It will also be appreciated that the edge of region two, points 24 through 26, provides an effective cross sectional area, represented by the imaginary line 26, which is approximately equal to A_{E1}, but still larger than A_{E2}. The entire wall structure between points 20 and 26 can be viewed as forming a geometric inflection in the exhaust gas flow path 16. The area between points 22 and 24 presents an increased cross-sectional area to the exhaust gas flow, thereby reducing blockage. The subsequent curvature back towards the inner wall 12 serves to realign the flow of exhaust gasses to maximize the nozzle noise reduction efficiency. The result is a segmented nozzle with distinct sonic and subsonic flow control regions yielding a net zero change in flow

characteristic and a net zero change in segment noise suppression effectiveness of the segmented exhaust nozzle 10.

[0022] While it will be appreciated that the outer wall 14 of the exhaust nozzle 10 has been illustrated as including the geometric influction surface, it will be appreciated that this surface could also be provided on the inner wall 12 of the exhaust nozzle 10.

[0023] Referring to Figure 3, a graph 30 illustrates the reduction in exhaust gas flow noise with the segmented exhaust nozzle 10 of the present invention during a flight test.

[0024] Figure 4 is a graph 32 illustrating the reduction in interior noise of an aircraft incorporating the segmented exhaust nozzle 10 of the present invention.

[0025] Figure 5 illustrates a graph 32 of the flow characteristic of the segmented exhaust nozzle 10 of the present invention as compared to a conventional exhaust nozzle flow 34 and a flow characteristic of a previously developed, segmented nozzle design 36. From Figure 5 it will be appreciated that the flow characteristics of the exhaust nozzle 10 closely match those of a conventional exhaust nozzle.

[0026] It will be appreciated then that the segmented exhaust nozzle 10 of the present invention provides a means to significantly attenuate the exhaust jet noise produced by turbofan engines, and thus help to meet increasingly stringent community noise requirements. Importantly, the exhaust nozzle 10 does not adversely impact the operation or operability limit related performance of existing large turbofan jet engines.

[0027] The segmented exhaust nozzle 10 is further capable of being used as a segmented nozzle in exhaust nozzles having an internal primary plug, such that no inner wall is present. In such an exhaust nozzle, the outer wall 14 would curve with reference to the imaginary center line C_L, since no inner wall would be present.

[0028] Those skilled in the art can now appreciate from the foregoing description that the broad teachings of the present invention can be implemented in a variety of forms. Therefore, while this invention has been

described in connection with particular examples thereof, the true scope of the invention should not be so limited since other modifications will become apparent to the skilled practitioner upon a study of the drawings, specification and following claims.